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SPONTANEOUS TRANSITION OF SLIDING FRICTION TO ROLLING FRICTION IN THE HIGH-TEMPERATURE TESTING OF REFRACTORY CARBIDES

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SPONTANEOUS TRANSITION OF SLIDING FRICTION TO ROLLING FRICTION IN THE HIGH-TEMPERATURE TESTING OF REFRACTORY CARBIDES

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ABSTRACT

Two specimens, both of vanadium or molybdenum carbide, were friction tested by being made to rub together in vacuum with simultaneous heating and subsequent cooling. When heated, the specimens manifested a decrease in mean friction coefficient, in one case from 0.6 to 0.3, then the onset of oscillations in the friction coefficient with a sharp rise in friction coefficient (to 0.85), and, finally, the spontaneous transition from sliding to rolling friction with a concomitant drop in the mean friction coefficient to 0.05. The effect is explained by a surface-geometric mechanism, whereby the surfaces in contact crumble at high temperature, ejecting balls of the tested material, which fit into pits or grooves and act as roller bearings.

The vacuum friction testing of specimens made from the same stock of vanad- /1057*
ium carbide VC or molybdenum carbide Mo_2C, following a procedure described earlier (ref. 1) (friction of tubular specimens against contact surfaces made in the form of a sphere of large radius) disclosed a peculiar kind of wear at high temperatures, where the sliding friction changed spontaneously to rolling friction.

*Numbers in the margin indicate pagination in the original foreign text.

The specimens of these materials differed from the basic series of specimens tested in reference 1 in the large width of the friction surface of the lower specimen (fig. 1). As a result, the probability of the products of specimen wear being carried away from the friction zone was somewhat diminished, because of: 1) an increase in the width of the contacting surface; 2) a decrease in the angle of inclination of the annular friction surface at its inside boundary; 3) a decrease in the space between the rod and inside opening in the lower specimen (inside diameter of 11 mm instead of 14 mm).

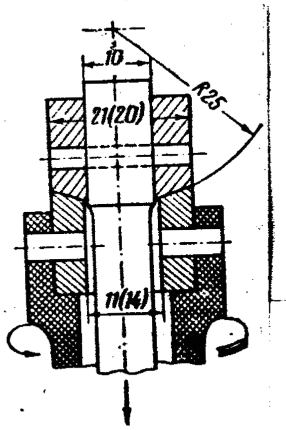

Figure 1. Diagram of the Friction-Testing Setup and Principal Dimensions of the Specimens.

A normal load was applied to the specimens by the bending of flat springs, which served simultaneously as measuring elements (resistance gauges were bonded on these springs). As a rule, the load applied initially varied only slightly during testing, falling off somewhat with heating due to the difference in thermal expansion of the parts to which the upper and lower specimens were attached (graphite rod and tube). In the tests conducted in the present investigation, the reverse pattern was observed after exceeding definite temperatures, i.e., the recorded load spontaneously made a sharp increase and became nonuniform (appearing as jumps in the record), and the friction moment decreased.

The spontaneous increase in load, evincing an additional bending of the loading springs, is a consequence of separation of the specimens, which could only occur as the result of a very intense impairment of the surfaces or, equivalently, the occurrence (or formation) of relatively large particles between the friction surfaces.

In the course of heating of the molybdenum carbide specimens, exceeding a temperature of 1250°C led to a rather abrupt increase in the friction moment for a fixed value of the load. At ~1700°C, the mean values of the friction coefficient climbed almost to 1.0, after which began a spontaneous increase in the load with a steep drop in the friction moment. The mean friction coefficient at this point first dropped to 0.19, then to 0.09. As a result of the enormous increase in load, the graphite pin used to fix the upper specimen on the rod was severed, and tests were not performed on the specimens during cooling. On 1058
separating the specimens after cooling, round particles of molybdenum carbide were found between the friction surfaces, photographs of these appearing in figure 2A (the larger particle has a diameter of ~1.5 mm). Consequently, during the rubbing process, after exceeding a definite temperature there occurs a spontaneous formation of round wear particles between the contacting surfaces.

The friction surface of the upper and lower specimens have three clearly marked and very distinct (in outward appearance) zones. They are quite evident in the photograph, shown in figure 2B, of the vanadium carbides (tested during heating and subsequent cooling). The outer, rather broad annular regions have an uneven rough surface, on which traces of slipping are not in evidence (fig. 2C, zone a). Near the inner edge of the specimens, opposite one another, are rather deep grooves with shiny smooth surfaces and no appreciable traces of slipping. At the edges of these grooves (projecting above the general level of

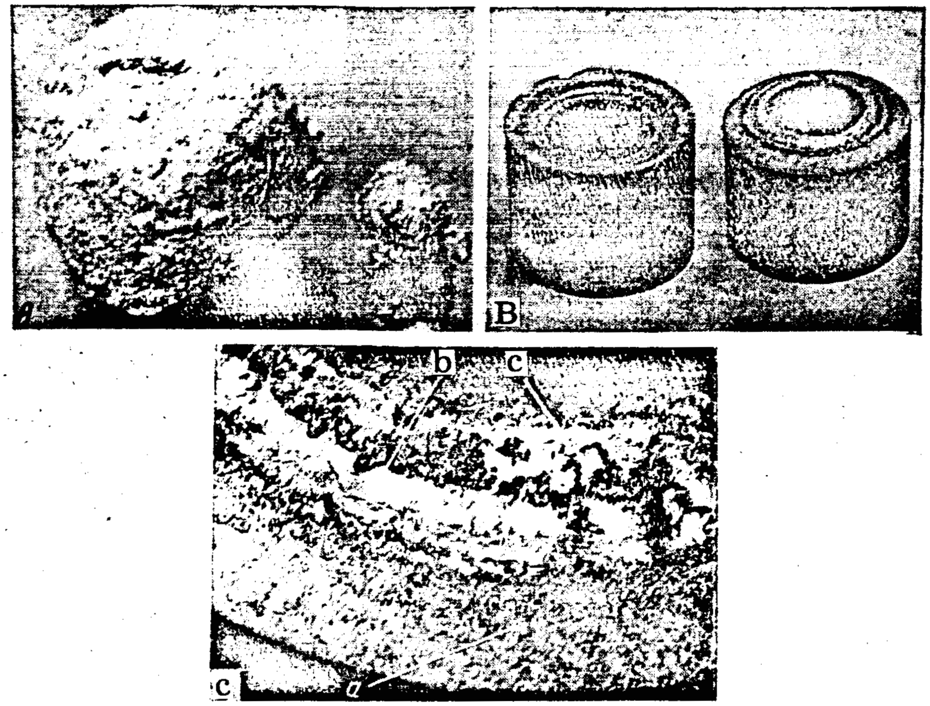

Figure 2. A) Round Wear Particles, Formed in the Rubbing of Molybdenum Carbide Specimens and Acting as Rolling Bodies (X-30). B) Outward Appearance of the Vanadium Carbide Specimens Tested. C) A Portion of the Friction Surface of the Lower Vanadium Carbide Specimen: a) Rough Uneven Surface; b) Grooves with a Shiny Smooth Surface; c) Smooth Even Surfaces (X 15).

the friction surfaces) are smooth, even, shiny portions on which slipping has occurred in the very last phase of testing.

The low values of the friction coefficient, rounded form of the wear particles, and shape of the grooves appearing on the friction surfaces of the upper and lower specimens are evidence that these particles must have rolled in the grooves during rubbing, acting like roller bearings (which have appeared of their own accord). But the presence of jumps in the recorded load is due to the fact that the particles are not perfect spheres and that there are irregularities and protrusions on the bottom of the grooves.

The mechanism of formation of the coarse round wear particles might be described as follows. As the temperature of the tested carbides is increased, the tendence for grabbing (as manifested in an increased mean value of the friction coefficient) increases and plastic deformation becomes possible. On attaining definite conditions (i.e., a certain relation between the grabbing tendency and the mechanical attributes), the particles that become separated on disintegration of the grabbing nodes become free to roll between the surfaces. The high tendency toward grabbing and, clearly, the low breaking strength under these conditions lead to growth of the particles, like the growth of a snowball when it is rolled in the snow at temperatures near freezing. This kind of wear is observed in the rubbing of rubbers and certain polymeric materials and might therefore be called, by analogy, "rolling" wear. The rolling bodies thus formed reach an equilibrium size appropriate to given conditions (temperature, friction path). In the relative displacement of the contacting friction surfaces, they roll around in pits dug thereon or on the friction surfaces of the grooves (fig. 3A), forming as a whole a kind of spontaneously generated roller bearing. /1059

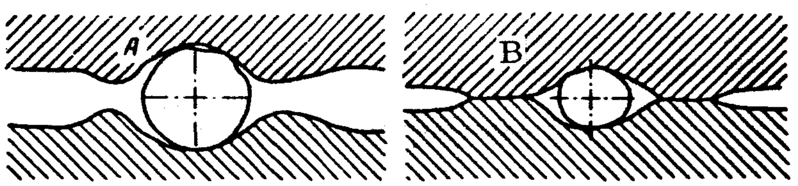

Figure 3. Friction Pattern: A) in Transition to Rolling; B) with Simultaneous Rolling and Sliding.

With a reduction in temperature, the tendency to grab becomes less and the conditions for restoring the dimensions of the rolling bodies disappear. As a result of their wear or separation, the reverse transition to sliding friction occurs, as evinced by the spontaneous reduction in load and change in character of the load record. The value of the friction coefficient in this case increases, but does not attain the values that occurred in heating. This permits the assumption that the rolling elements can be preserved at low temperatures as well.

The occurrence of residual rolling is possible when the rolling bodies located in the grooves are worn down to dimensions that do not impede direct contact (and mutual sliding) of the friction surfaces. In this case, shown schematically in figure 3B, part of the normal load will be perceived as before by the rolling bodies and the total friction force will be the sum of sliding friction and rolling friction. Apparently, this pattern can exist only when /1060 the temperature is lowered to a value governing the limiting degree of friability of the carbide at which rolling particles become detached.

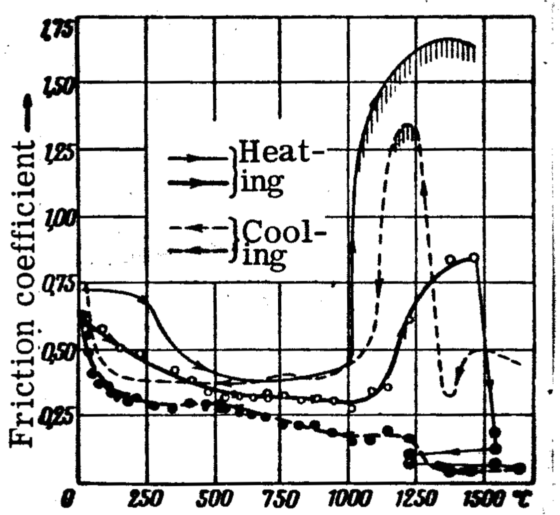

Figure 4. Temperature Dependences of the Friction Coefficient, Obtained in the Rubbing of Vanadium Carbide Specimens in Vacuum (During Heating and Cooling).

Figure 4 shows the results of the last (third) test on vanadium carbide specimens in vacuum during heating as well as subsequent cooling. The curves are drawn for the mean values of the friction coefficient (heavy lines) and for discontinuous-type sliding for its maximum values (fine lines). The verticle strokes on the line of maximum values of the friction coefficient indicate the presence of continuous friction autooscillations of large amplitude under the given conditions. The experimental points are plotted only for the mean values of the friction coefficient. The points for which rolling is typical are marked by small circles.

In heating, the mean value of the friction coefficient decreases smoothly from 0.60 at room temperature to ~0.3 at 1000°C (minimum value). The transition to continuous autooscillations in heating was observed during recording at 1015°. The increase in temperature was accompanied by an increase in amplitude of the autooscillations and, even moreso, in the mean friction coefficient - to 0.85 at 1460°. Further heating (to 1545°) induced a transition from sliding to rolling friction with all the outward manifestations described above. The amplitude of the oscillations fell off sharply, and the mean value of the friction coefficient dropped to 0.13. With quick freezing of the specimens to 1225° and subsequent heating to 1635°, the rolling friction remained very stable, the mean friction coefficient dropping to 0.05.

During cooling, the rolling friction retained its magnitude down to about 1300°, after which began a transition to sliding friction, which was completed for the most part at a temperature of ~1225°. A further reduction in temperature was accompanied by a smooth increase in mean value of the friction coefficient, completing its steep rate of increase near room temperature. The smaller values of the friction coefficient during cooling are due to the fact that after the cessation of pure rolling they provided a partial contribution to the friction down to room temperature according to the pattern illustrated in figure 3B.

It follows from a comparison of the series of three tests on vanadium carbide specimens that each succeeding experiment is characterized by a more clearly pronounced high-temperature transition from sliding friction, with a high mean value of the friction coefficient, to rolling friction with a relatively low friction coefficient. This is clearly the result of an accumulation of modifications in the geometry of the contacting friction surfaces (formation of opposing annular grooves on the friction surfaces) and the removal from the specimens of impurities ejected at high temperatures.

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